A Survey of Specular Reflection Removal Algorithms

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***Abstract*— Removal of specular reflection also called specularity or highlights from an image is very important before the image is processed or analyzed by computer for image processing, computer graphics and computer vision because it is considered as part of the image by the computer. Removal of specular reflection is important because when there are specular reflections in the image it causes errors in the results of many algorithms of computer vision and image processing. Due to specular reflections in images shapes in images get distorted therefore all shape detecting algorithms and algorithms based on shape detection, boundary detection results in erroneous outputs. Removal of specular reflection includes detection of the reflection or reflections in the given image and then changing those pixels with some other color pixel based on the other portions of the image which are not faulty. There exist many different techniques for the detection and removal of specular reflection. In this paper, some of such techniques and approach to tackle the problem are discussed.**

Keywords—specularity, inpainting, bilateral filtering, high speed imaging.

I. INTRODUCTION

Specular reflection in the image has been a challenge in the field of computer vision and image processing from a very long period. It is defined as a type. They generally seem like surface features, but they are just artefacts that are caused due to changes in illumination from different angles [1]. Removing specular reflection can be seen as a problem of taking out information that is present in an image and then applying various transformation techniques to convert the information into meaningful representations. Specular reflection removal is quite important before image analysis and processing as applying processing algorithms like segmentation, recognition etc. to an image containing specular reflection may lead to significant inaccuracies in the results. It also reduces the robustness of certain algorithms and as a result, makes the algorithms less effective and reducing their applicability. They can also hide various defects in images which will remain hidden during inspection [2]. Specular reflection, especially on medical images like cervigrams, can result in misdiagnosis of cervical cancer or other types of diseases. So it can be seen easily that reflections in images cause a lot of problems ranging from making algorithms ineffective to life-threatening. Therefore it is crucial to develop effective algorithms and hardware solutions.

One of the methods is to use a polarizing filter. But it is not convenient enough as not everyone possesses a polarizer every time they try to capture an image or take a photograph. Other Methods have also been studied like changing the position of the light source [3] or changing the position of the camera instead of a light source [4] in order to separate the specular reflection components. But, both the above-mentioned methods require the change in the position of the light source or the camera in the image processing system, thereby producing a huge strain or limitation when a picture is being taken. Here the speckle removal algorithms take the lead. In this paper, we discuss the various algorithms developed for specular reflection removal.

II. METHODS

The papers selected were taken from various renowned publishing websites like IEEE, Springer, and Elsevier. The selected papers were then evaluated and papers with significant results and good accuracy were further taken into consideration. The papers were selected from the past 20 years. The algorithms discussed in the paper mainly vary by virtue of their applications and implementations. Some algorithms perform better in situations when reflections are caused due to moisture on the surface, some perform better when reflections are caused due to the material of the object,

some when reflections occur during medical imaging, while others perform better in general conditions.

III. Algorithms and Techniques

A. Light Field Imaging Based Accurate Image Specular Highlight Removal

Haoquian Wang et. al. have developed a Light Field imaging based image specular highlight removal algorithm [1]. Their algorithm works well in complex scenarios that occur in real life. This algorithm take advantage of the light field of Imaging Technology (Lytro ILLUM). The image is first captured (with specularity present) by the light field camera. Then depth of the image is accurately analysed and estimated and the specular pixels are then classified into two categories namely, "Unsaturated" and "Saturated" using a straightforward and concise thresholding strategy. For depth estimation and to achieve refocusing, utilisation of a depth estimation algorithm by combining/integrating both the correspondence and defocus cues has been done. 4D epipolar image (EPI) is exploited after deriving it from the LF data, making shears in order to operate refocusing. Then the responses of the two cues are computed using a single contrast-based approach presented in the paper. Both the locally estimated cues are then combined with a measure of confidence and global depth estimation is computed using MRFs to obtain the final result. At last, multiple views are subjected to color variance analysis and the two categories are used to recover diffused color information by conducting local color refinement individually on the two categories. The method is then experimentally evaluated by comparing them with the existing methods based on the light field dataset along with the standford light field archive, thus verifying its effectiveness.

$$D_{\alpha}(x,y) = \frac{1}{|W_D|}\sum_{(x^f,y^f)\epsilon W_D} |\Delta\bar{I}_x(x^f,y^f)|$$

B. An Image-Correction Method for Specular Reflection Removal Using a High-speed Stroboscope

Toshiaki Tsuji [5] suggests a method for separating diffused reflection components from specular reflection components. The author's group developed a method of separating specular reflection components present in a high-speed video from diffused reflection components. A luminance variation (because of the flicker of a strobe) based estimation technique has been used. But the issue with this method is that a new specular reflection component is produced by the strobe. An algorithm is suggested to remove this specular reflection produced by the strobe. The arithmetic algorithm consists of the two processes mentioned below:

- Specifying the highlight area
- Compensation in the highlight area

The original color of the object cannot be defined accurately as the highlight area is produced by strong specular reflection components caused by the light source. This method also solves the problem intensity discontinuation due to image synthesis with the different light source. Experimental results are then used to show the efficiency and validity of the algorithm.

C. Removal of Specular Reflection in Large Scale Ocean Surface Images

Shengke Wang et. al. used an image impainting technique for removal of specular reflection in large scale ocean surface images [7]. After detection of specular reflection in an image for removing reflection area image impainting technique proposed by Alexandru Telea based on Fast marching method is used [8]. In this algorithm filling of the specular reflection is done from the boundary pixels that decreases the size of area and repetition of filling boundary decreases the size of the area of specular reflection to zero. A pixel at the boundary is changed depending upon surrounding pixels of the image which are already correct. Effect of a surrounding pixel to the pixel to be corrected is based on the value of the surrounding pixel and its weight. Weight for a pixel is based on the distance between that pixel and the pixel to be corrected.

$$I(p) = \frac{\sum_{q\epsilon B_{\varepsilon}(p)} w(p,q)[I(q) + \nabla I(q)(p-q)]}{\sum_{q\epsilon B_{\varepsilon}(p)} w(p,w)}$$

Where *I* is impainting, *p* is the point to be inpainted. B_{ϵ} is the surrounding region where *q* points exist. *q* are the points in the surrounding region that don't contain specularity. *W(p,q)* is the weight of the points in B_{ϵ}.

D. Removal of Specularities Using Color and Polarization

Shree K. Nayar et. al. proposed an algorithm for removal of specular reflection that uses polarization and color for separation of the two components of reflection, diffused and specular [9]. Most of the methods are either based on color or polarization. This algorithm applies new constraints on speculatrities by simultaneously using both color and polarization. Color of specular component is determined locally using polarization thereby constraining the diffused color at a pixel to a linear subspace of a single dimension. Neighbouring pixels whose color do not changes much with the pixel are found using this subspace. Information of diffuse color from consistent neighbours in subspace determines the value of the diffuse color of the pixel. This method of specular reflection removal can be used for specularity removal from direct source illuminations as well as interreflection between points in the scene. Neighbours having same diffuse color for each point is required for the algorithm to be used. The magnitude of neighbouring pixels may have a different magnitude of diffuse color but the direction in color space must be the same. The advantage of this algorithm over other methods is that the diffuse component in the image which is under the specularity region is not considered to be constant in the whole region. Another great advantage is that the diffuse component under the highlight region can be a texture and algorithm performs well in removing specularity. Reflection depends upon Fresnel ratio which is dependent on the angle of incidence and the

material of the surface on which light is incident, this algorithm also performs well in case of reflection of different Fresnel ration in a particular specularity region. So, if in a region of specularity there are reflections due to different materials it can also be removed using this algorithm.

E. Specular Reflection Reduction with Multi-Flash Imaging

Ramesh Raskar et. al. [10] proposed a technique to solve the problem of specular reflections. A camera with multiple flashes is used in this method. The camera will not be dependent on a single image of a scene rather it captures multiple images of a particular scene with different flash for each image. One flash at a time is kept in ON state and all the other flashes are kept in OFF state. This technique uses the phenomenon that position of specular reflection changes with the position and angle of incident light. So, there will be n number of images captured with n flashes, all at a different position that leads to specularity at a different position on each image. When captured images are combined, some highlights may overlap or may not overlap. This results in the three cases mentioned below:

- Some highlights remain distinct (no overlapping)
- Some highlights partially overlap.
- Some highlights overlap completely.

The proposed method works well with the first two cases but fails in the third case. It is to be noted that the boundaries/intensity edges around the highlights do not generally overlap even though specularities do overlap in input images. The principle idea of the approach is to take advantage of the variation of the gradient in n images, taken under n separate lighting conditions at the location of the given pixel, (x, y). If the mentioned pixel (x, y) is in the specular region in the case of no overlap or partial overlap, the gradient because of the specularity edges will be high in a minority or in only one of the n given images. A variable named I_k has been defined that represents an input image taken using a light source *k*, where *k* ranges from 1 to *n*.

This formula separates out the maximum intensity components from the image. These maximum intensity components are specularities.

This formula calculates the median of pixels at location (x, y) of every image.

F. Real-Time Specular Highlight Removal Using Bilateral Filtering:

Qingxiong Yang et. al. [6] Suggests a method for real-time specular reflection removal based on the observation that maximum diffuse chromaticity changes quite smoothly in local patches. This property is used to then estimate the maximum diffuse chromaticity values by the usage of low pass filter. The low pass filter is applied directly to the maximum fraction of the color components present in the original image, such that the propagation of maximum diffuse chromaticity values is done from diffuse pixels to the specular pixels. Computation of diffuse pixel at each pixel is then done as a nonlinear function of the maximum diffused chromaticity that was estimated. If edge-preserving filters are used, this method can be extended for multi-color surfaces. Joint Bilateral filtering can be used to smoothen the maximum chromaticity $\sigma_{max,}$. As for the smoothing guidance, maximum diffuse chromaticity Λ_{max} is used. The maximum diffuse chromaticity can be defined as:

$$\Lambda max = \max(\Lambda r, \Lambda g, \Lambda b).$$

Recent developments in the field of fast bilateral techniques make the method run nearly 200 times faster than the state-of-the-art on the standard CPU. This technique is capable of processing high-resolution images at video rate and therefore is suitable for applications that work in real time. Also, the diffused reflections that are estimated will be locally smooth, does not result in noticeable artefacts.

G. Correction Of Specular Reflection By Recursively Applying Smoothing Spatial Filter

Generally, the detected specular reflections are considered as noise and we use smoothing spatial filter to either remove or smoothen this noise in the image. By this filter, the reflections can be blurred that is the filter covers places on the original image, and divides by the sum of all kernel elements, then multiplied with input pixel intensity and kernel values [11] and the formula for this filter is

$$C = \frac{1}{N}\{M(1)I(1) + M(2)I(2) + \cdots M(N)I(N)$$

$$C = \frac{1}{N}\sum_{k=1}^{N}\{M(k)I(k)\}$$

Here the c is renewed average and N is multiple of length and width [12].

The result will be an average value as it is divided by the multiple of length and width (N)

To have a very smooth process we have to consider to consider mask elements as 1 and the above expression will be changed as

$$C = \frac{1}{N}\{I(1) + I(2) + \cdots I(N)$$

$$C = \frac{1}{N}\sum_{k=1}^{N} I(k)$$

Therefore the final result of this filtering will be an average value as it divides with N after adding all intensities of the pixels. Our main task is to remove or minimize the specular reflections but after this process the image will be blurred as

it is not our main aim we have to update the intensity of pixels present in the specular reflection area which is found through perception neural net as it was shown before but not change the whole intensity of the pixel.

H. *Automatic Detection Of Specular Reflections In The Cervix Images*

Here the specularities are detected in cervix images using intensity, saturation and gradient information and identification of highlighted region is done in a two stage segmentation process. First, coarse regions which have the reflections are found and second probabilistic modelling and segmentation are done to perfectly select the coarse regions. For the resulting region, a simple filling scheme is proposed.

Highlights are most likely to found in the SR regions which are coarse regions, these specularities normally have low saturation values (S) and very high intensity (I) values, so initial regions can be found by using thresholds on I and S [13].

$$I = \frac{R+G+B}{3}$$

$$S = 1 - \frac{\min(R,G,B)}{I}$$

Now a precise selection of previously defined coarse region is required for this they used Gaussian mixture model in which each pixel is considered as the 2-d vector and are these pixels are grouped as homogeneous regions and each region is represented as Gaussian distribution [14].

$$f(x) = \sum_{j=1}^{k} a_j \frac{1}{\sqrt{(2\pi)^d |\Sigma_j|}} exp\left\{-\frac{1}{2}(x-\mu_j)^T \sum\nolimits_j^{-1} (x-\mu_j)\right\}$$

For the final step, a filling scheme is used, which removes the strong gradients while making sure the original texture is not affected.

I. *Removing Specular Reflection Components For Robotic Assisted Laparoscopic Surgery*

In this paper, they propose that at first all the chromatic information should be collected for the spatio-temporal volume so that this information can be used to remove the specular reflections on the epicardial surface of the heart while performing a robotic laparoscopic surgery while preserving the original image structure, By the above collected information the pixel intensities can be shifted for separating the specular and diffuse image components. Mostly all the processes that remove the specular reflections normally have a little bit of image data lost in the process but here as there are thin nerves we cannot use normal methods we have to rather use a method that can collect as much as the information of the image by extending chromaticity [15]. Here I_c^{diff} is the diffuse component of reflectance and $\Lambda = \Lambda_r \Lambda_g \Lambda_b$

It is clear that chromaticity of the diffuse pixels is always higher than that of the specular pixels, By making use the image pixel distribution projection into D space the diffuse reflectance component can be found as shown in the above formula and stored in a spatio-temporal volume.

J. *A Video Stream Processor For Real-Time Detection And Correction Of Specular Reflection In Endoscopic Images*

In this paper, the detection and correction of the specular reflections are by an algorithm called inpainting algorithm. Correcting a frame represents removing all the specularities that determined before and replacing them for neighbourhoods information, the common way is to use algorithms like Navier-stokes algorithm [16]. As it has many loops through a frame it requires large amounts of memory and computational power, so we use single frame memory architecture. It operates line by line

1. A line of the frame is stored.
2. We collect three data information, they are pixel value before the specular region P_b, pixel value after specular region P_c and the region's width
3. Now we can kind linear show ***a*** as:

$$a = \frac{P_c - P_b}{w}$$

4. The leftmost pixel has index 0 in the specular region and p_0 is given value P_b+a. the new value of all other pixels are

$$P_{i+1} = P_i + a$$

As it only operates in the horizontal direction it is necessary to correct the vertical dimension. This is done with a smoothing window by changing modified pixels with the average of its neighbours and it may have a little delay but it can be considered negligible while the time of real operation.

IV. Comparision Table

Authors	ALGORITHM	TECHNIQUE USED	ADVANTAGES
Wang et. al.	**Light Field Imaging Based Accurate Image Specular Highlight Removal**	• Based on Light Field imaging technology	• Works well in complex real-life scenarios
Tsuji et. al.	**An Image-Correction Method for Specular Reflection Removal Using a High-speed Stroboscope**	• Luminance variation based estimation technique	• Solves discontinuous intensity problem due to image synthesis with a light source
Wang et. al.	**Removal of specular reflection in large scale ocean surface images**	• Image Inpainting based on Fast Marching Method	• Works well with underwater images of oceans
Nayar et. al.	**Removal of Specularities Using Color and Polarization**	• Based on color and polarization of surrounding pixels	• Removes direct reflection as well as inter-reflection • Works well in images with texture.
Raskar et. al.	**Specular Reflection Reduction with Multi-Flash Imaging**	• Uses multi-flash camera (hardware), the position of specularity changes with a change in angle of incidence of light.	• Removes distinct highlights. • Removes partially overlapped highlights
Yang et. al.	**Real-time Specular Highlight Removal Using Bilateral Filtering**	• Based on the observation that maximum diffuse chromaticity changes quite smoothly in local patches	• Capable of processing high-resolution images at video rate. • Suitable for applications that work in real time.
Lehman et. al.	**Correction of specular reflections by recursively applying a smoothing spatial filter**	• Using smoothing spatial filter to remove noise	• The new image will not be blurry as the whole intensity of the pixel is updated.
Gonzalez et. al.	**Automatic detection of specular reflections in the cervix images**	• probabilistic modelling and segmentation	• As the filling scheme is used original texture is not affected
Bertalmio et. al.	**Removing Specular Reflection Components for Robotic Assisted Laparoscopic Surgery**	• Using chromatic information and store it in spatio-temporal volume	• The original image is distorted in the process as only image data is collected.
Lin et. al.	**A Video Stream Processor for Real-time Detection and Correction of Specular Reflections in Endoscopic Images**	• we use single frame memory architecture	• It takes very less memory and doesn't need high computational power

Table 1

Conclusion

In this paper, we have discussed various specular reflection removal algorithms. Some of these algorithms perform better in certain conditions while others are effective in general conditions. Some are more accurate while others are less accurate but require less computation power and perform their operation in very less time. Characteristics of various materials in the real world makes specular reflection inevitable. Currently, existing specular reflection removal methods are quite effective and achieve good separation of specular components, but are limited to their applicability conditions. Most of the techniques mentioned above rely on specific reflection model. This along with other problems like noise sensitivity make these algorithms less effective and reduce the range of their applicability. More accurate and robust algorithms are required which can overcome the limitations of the current methods. Our future work will involve developing a more general and robust algorithm for specular reflection removal which overcomes the limitations of most of these algorithms along with maintaining its accuracy.

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